ALICE tracking system

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Third International Workshop for Future Challenges in Tracking and Trigger Concepts

Outlook

Detector description

Reconstruction algorithm

Detector calibration

Detector performance

Reconstruction parallelization

Detector description

The ALICE experiment

Dedicated heavy-ion experiment at LHC

- Study of the behavior of strongly interacting matter under extreme conditions of high energy density and temperature

Proton-proton collision program

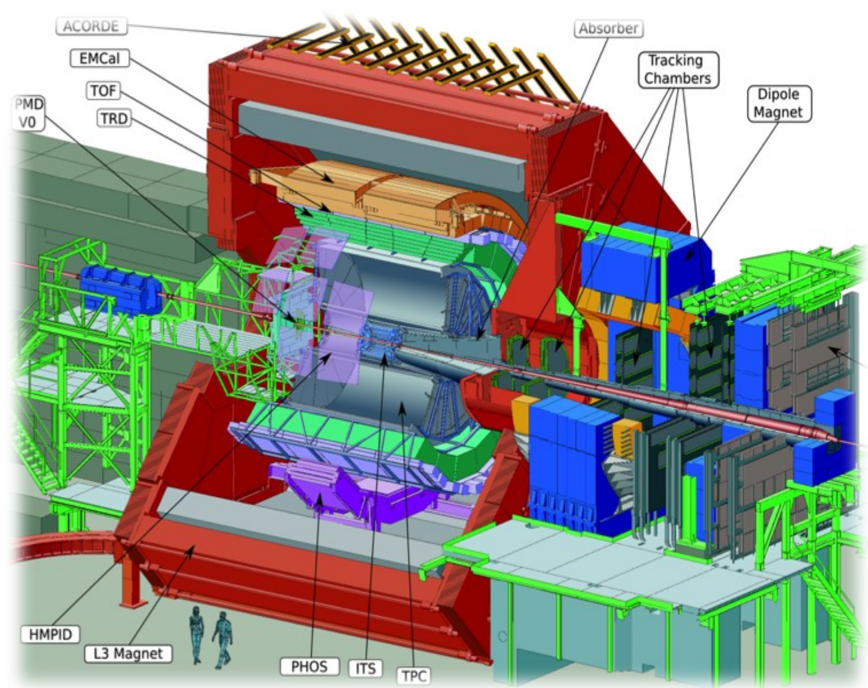
- Reference data for heavy-ion program
- Genuine physics (momentum cut-off < 100 MeV/c, excellent PID, efficient minimum bias trigger)

Barrel Tracking requirements

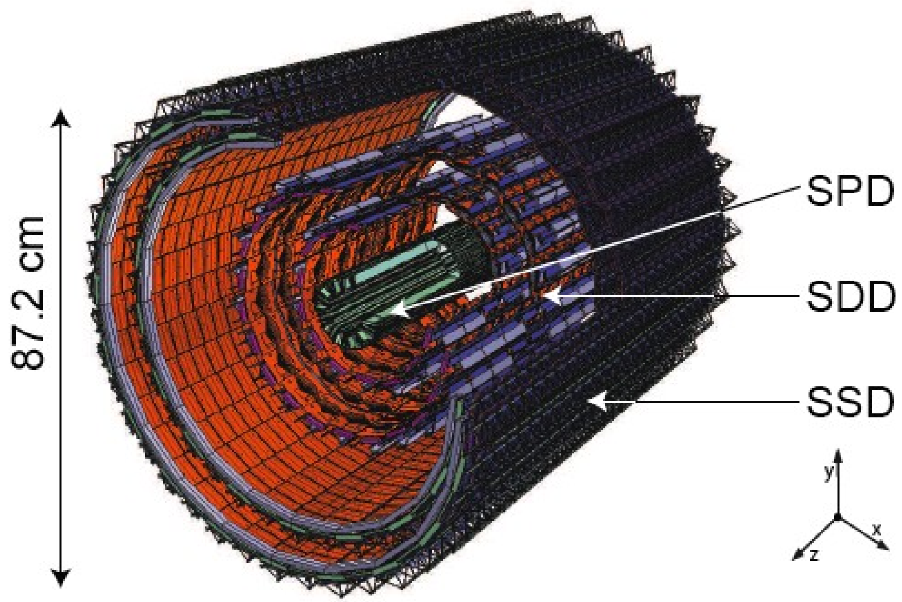
- Pseudorapidity coverage **$|\eta| < 0.9$**
- Robust tracking for heavy ion environment
- Mainly 3D hits and up to 159 (TPC)+ 6 (ITS) points along the tracks
- Wide transverse momentum range (100 MeV/c – 100 GeV/c)
- Low material budget (13% X_0 for ITS+TPC)
- Large lever arm to guarantee good momentum resolution at high p_t

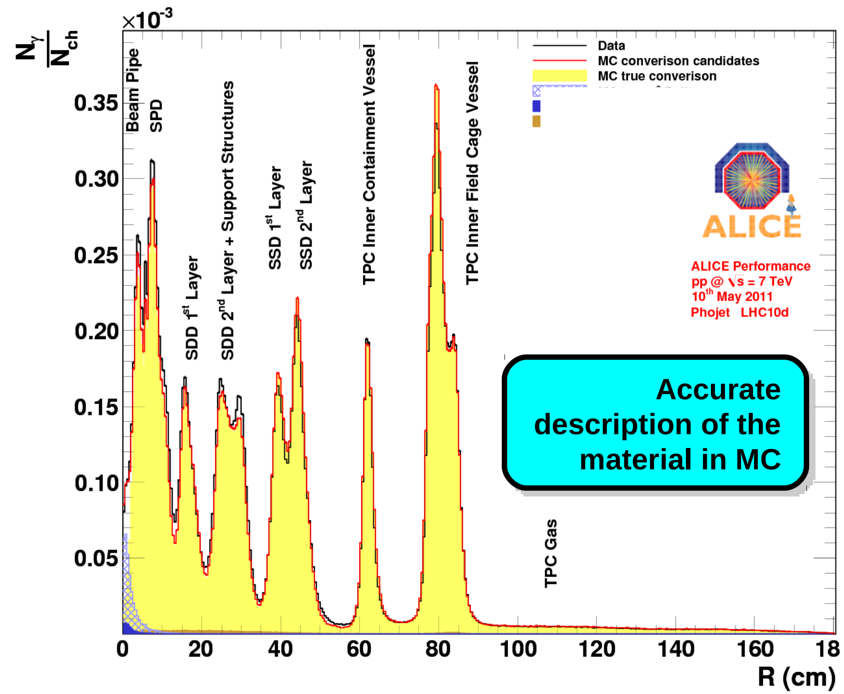
PID over a wide momentum range

- Combined PID based on several techniques: dE/dx, TOF, transition and Cherenkov radiation



Inner Tracking System (ITS)

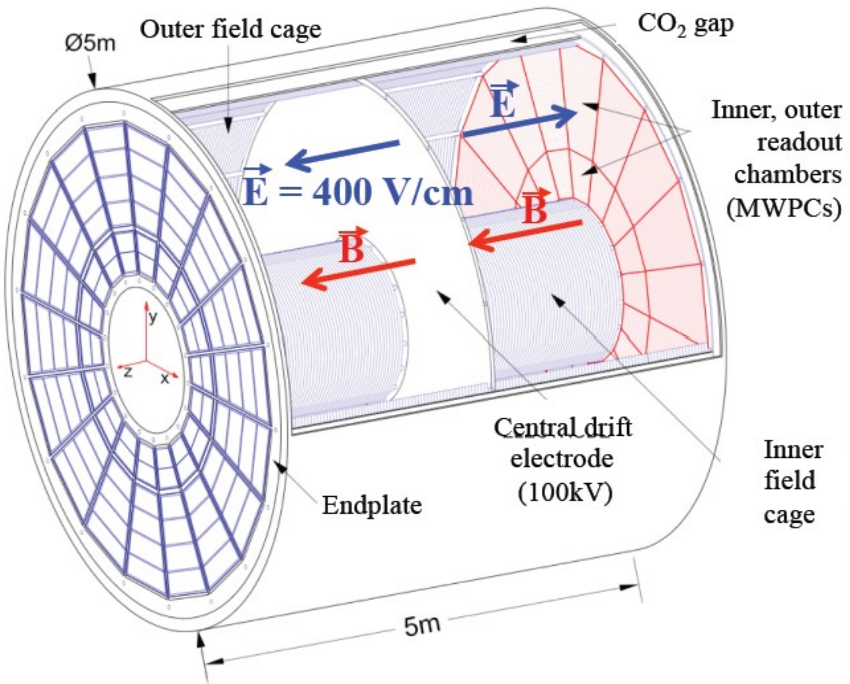




Layer	Det.	Radius (cm)	Length (cm)	Surface (m2)	Chan.	Spatial precision (mm) rφ	Spatial precision (mm) z	Cell (µm2)	Max occupancy central PbPb (%)	Material Budget (% X/X_0)	Power dissipation (W) barrel	Power dissipation (W) end-cap
1	SPD	3.9	28.2	0.21	9.8M	12	100	50x425	2.1	1.14	1.35k	30
2		7.6	28.2						0.6	1.14		
3	SDD	15.0	44.4	1.31	133 K	35	25	202x294	2.5	1.13	1.06k	1.75k
4		23.9	59.4						1.0	1.26		
5	SSD	38.0	86.2	5.0	2.6M	20	830	95x40000	4.0	0.83	850	1.15k
6		43.0	97.8						3.3	0.86		

Time Projection Chamber (TPC)

TPC: main tracking device in ALICE



Largest TPC:

- Length 5 m
- Diameter 5 m
- Volume 88 m^3
- Detector area 32 m^2
- Channels ~570 000
- 72 Readout Chambers (32 inner - IROC, 32 outer - OROC)
- Gas Ne/CO_2 90/10%
- Field 400 V/cm
- B-field: 0.5 T
- Gas gain ~ 10^4
- Track position resolution σ= 0.15 mm
- Diffusion: σ_t= 2.50 mm/√m

Pad readout geometry optimization:

- Occupancy
- Space point resolution
- dEdx resolution

Constraints:

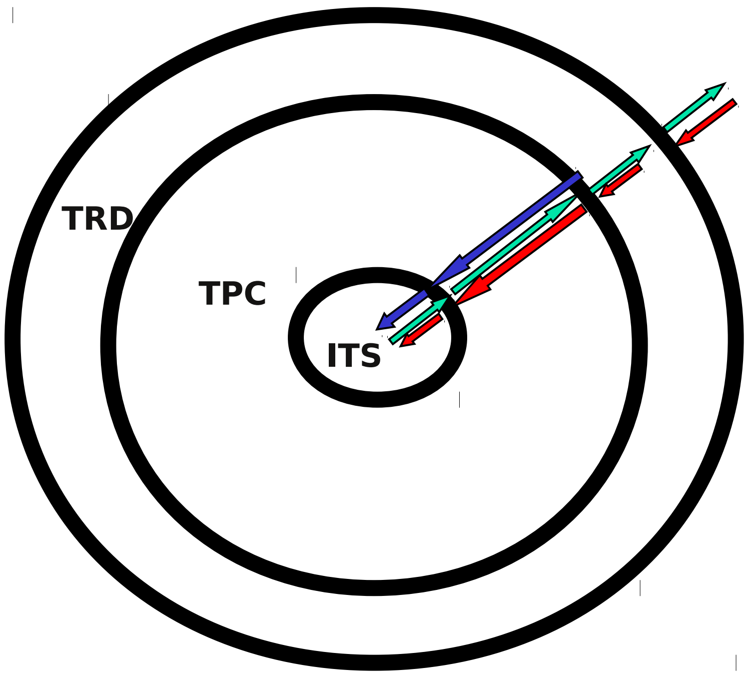
- Signal over noise
- Number of channels

159 measurements along trajectory *

- IROC: 4x7.5 mm (63 rows)
- OROC: 6x10 mm (64 rows) and 6x15 mm (32 rows)

Reconstruction algorithm

Reconstruction strategy – Combined tracking



Kalman Filter tracking approach chosen:

- Space points - clusters reconstructed before tracking
- Simultaneous track recognition and reconstruction
- Natural way to take into account multiple scattering, magnetic field inhomogeneity
- Possibility to take into account mean energy losses
- Efficient way to match tracks between several detectors

Kalman tracking in 3 iteration:

- Inward tracking – TPC-ITS
- Back propagation –ITS-TPC-TRD-PID detectors
- Refit tracks towards the vertex (TRD-TPC-ITS)

*Algorithm optimized for reconstruction of primary tracks. For decay topologies extended versions of algorithm used.

Main assumptions - Space points used for Kalman filtering:

- Gaussian errors with known sigma
- Errors between layers are not correlated

TPC reconstruction (0)

Local occupancy up to 10 % (dN_{ch}/dy ~ 1600):

- Cluster unfolding necessary

Non Gaussian error of cluster position:

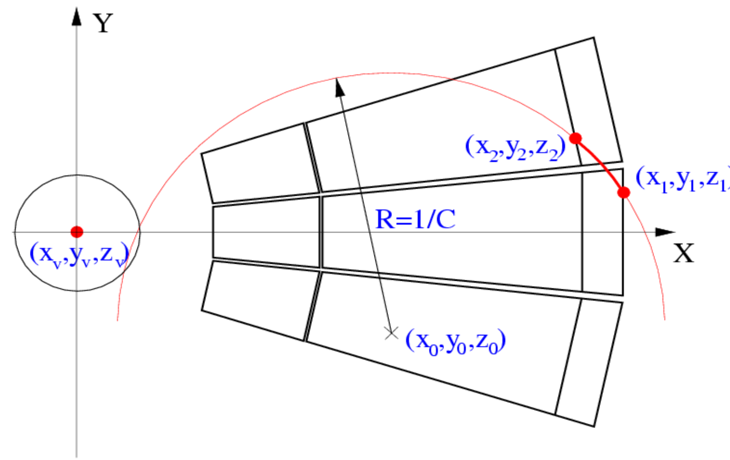
- The space point resolution to be calibrated as a function of the cluster and track topology. For overlapping clusters (extended shape or clusters belonging to more than one track) cluster position error correspondingly enlarged.

The occupancy in the track prolongation space significantly smaller than in digit space:

- In case good initial track hypothesis seed provided, the probability of fake space point association is small.

The TPC gas gain is time dependent:

- The probability to produce a cluster at given layer (pad-row) is also time (gain and dEdx) dependent and vary in the range from 70-100 % ==> Seeding procedure repeated several times in different TPC regions to obtain close to 100 % efficiency.



Generate a track seed starting from the 2 (primary track seeding) or 3 (secondary tracks seeding) space points

Iterate the following sequence:

- Extrapolate and look for compatible measurements.
- If there is none, go on.
- If there is one, take the most compatible one and make an update.
- If no compatible measurements can be found in several active layers, stop the track candidate.

TPC reconstruction (1)

Seeding Algorithm repeated several times starting from the 2 (primary track seeding) **or 3** (secondary tracks seeding) **space points**

Seeding in slice windows:

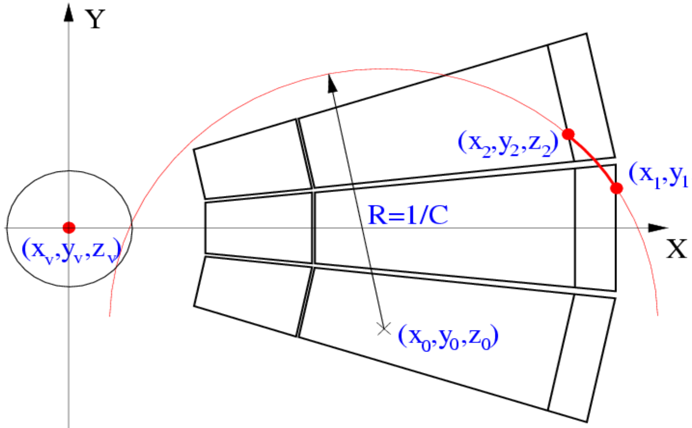
- Starting from the outermost (159) pad-row
- Last seeding pad-row given by minimal amount of clusters (64) - pt down to 100 MeV
- Clusters belonging to the golden tracks excluded from following seeding algorithm

CPU consumption minimization:

- Fast seeding with vertex constraint applied first (N^2 problem), seeding without the vertex constrain (N^3 problem) done after TPC cleaning

Cluster finder efficiency ~ 70-100 % (gain/time dependent). One layer seeding efficiency ~ 50-100 %

- Seeding procedure repeated several times in different TPC regions to obtain close to 100 % efficiency.



Track hypotheses clean up done at the end of the TPC tracking at each tracking iteration

Tracks with significant amount of shared space points rejected. Only “best” hypotheses kept

Special treatment of the decay topologies inside of the TPC (decays/Kinks and interaction). Tracks refitted towards to the vertex.

- Identified decay topologies used for the K and π identification

ITS tracking – Combinatorial Kalman Filter

The ITS “digit” occupancy (1-4 %) smaller than in case of the TPC. Cluster unfolding not the critical issue. But, significant occupancy in the track prolongation roads. Mainly for low momentum tracks (search window ~ 1/p)

Combinatorial Kalman Filter chosen

Use a **TPC extrapolated track as a seed**.

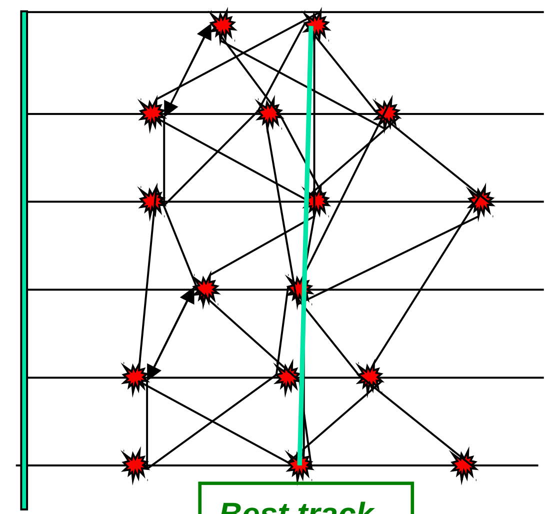
- * The ITS standalone tracking also implemented, but combined tracking more robust - significantly smaller amount of fake tracks

Iterate the following sequence:

- Extrapolate and look for compatible measurements.
- For each compatible measurement, generate a branch and make an update.
- Generate a branch with no update (**missing space point**)
- If a branch contains no updates for a number of layers,drop the branch.
- Drop the worst branches, and drop branches below some quality limit.
  - The total number of branches limited

Cleanup selecting the “best” branch using global information

- Additional information about the overlap with concurrent TPC tracks used – **conflict resolving algorithm** (maximizing the likelihood of pairs of tracks)
- For V0 topology (K0s, Λ, γ) the position of the decay vertex taken into account.



Best track (maximal likelihood)

ITS tracking: special case of primary tracks without conflict with concurrent TPC seeds

ALICE TPC calibration

TPC performance - space point resolution

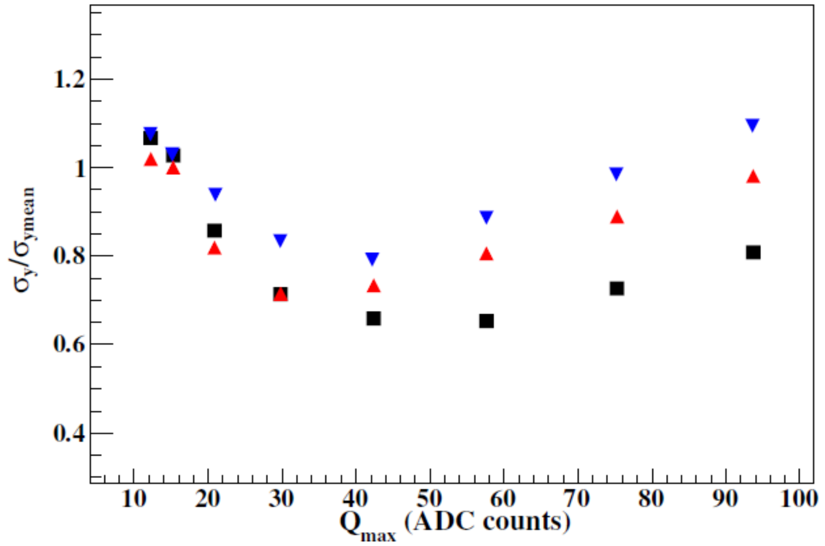
Up to 159 space points measured with the typical position resolution of about σ ~ 0.6 mm (for high momenta tracks small inclination angle)

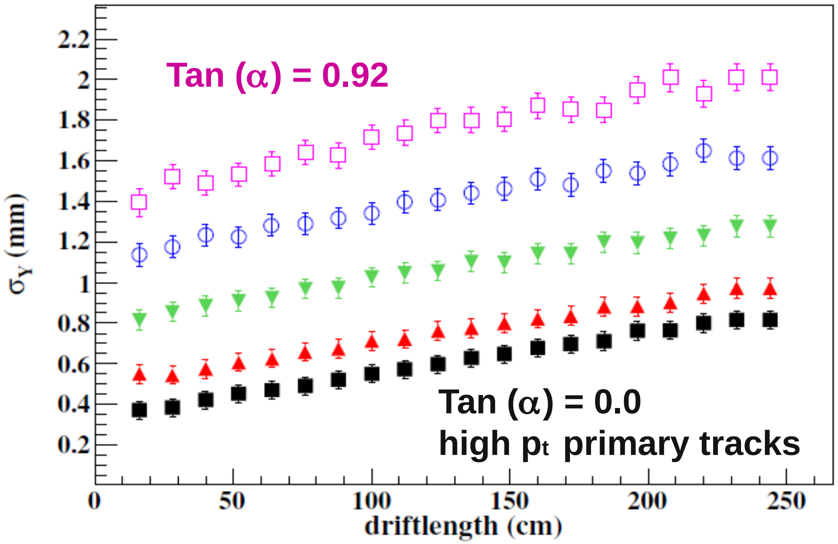
- **Track extrapolation precision** at the entrance of the TPC **of about σ ~ 0.15 mm** in both directions

Space point resolution depends on

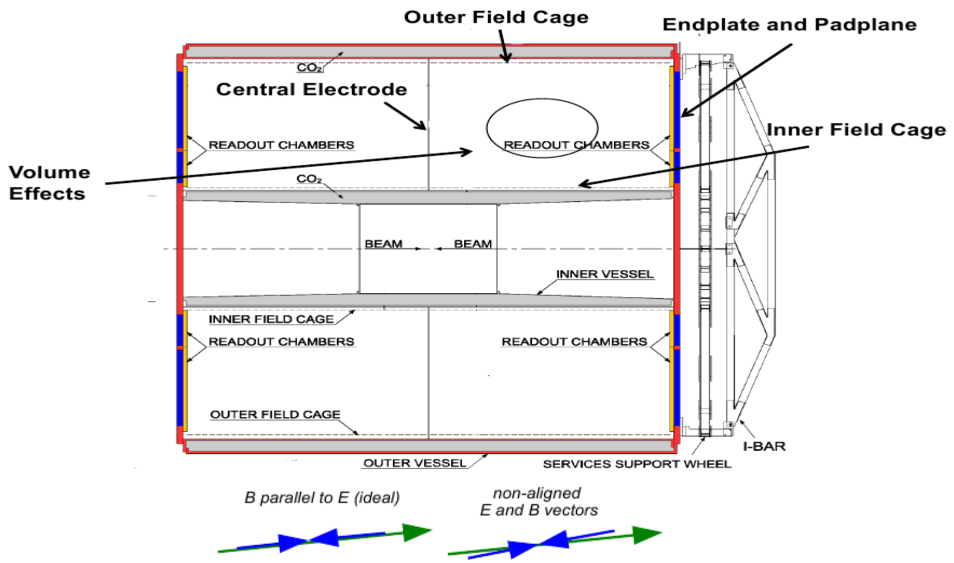
- The drift length
- The track inclination angle α
- The charge deposited Q
- Pad geometry (mainly pad length)

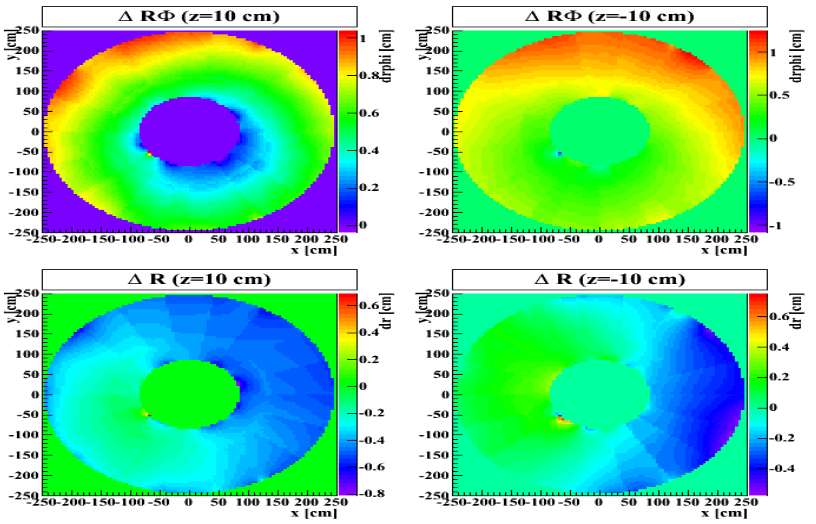
Requirement - the TPC alignment and the space position distortion calibration should be optimally kept below σ ~ 0.15 mm





TPC distortions





The TPC was internally mechanically **aligned to the 0.1 mm** level

Biggest observed distortion in the bending plane due to the ExB effect

- **B field inhomogeneity** – distortions up to **8 mm**
- **E field nonlinearities due misalignments** – distortions up to the **6 mm**
- **E and B field main component misalignment** – distortions up to **2 mm**

Right plot - resulting space point correction map as used currently in the Alice reconstruction

- The ExB effect time dependent (pressure, temperature, gas composition) – parameters updated on the run level

TPC space point correction framework developed - ALICE & STAR collaboration

- Physical (numerical solution of the Poisson equation) and effective distortion models

TPC distortion/alignment fitting

Assumptions:

- Space point distortion transformation commute (the order of applying of corrections is not important)
- Space point distortion can be approximated as a linear combination of the “partial distortion” functions with given parameter:
  - $\Delta = \Sigma$ ki Ei
- Space point distortion not directly observed. We define the set of observables O.
  - ΔO = Σ ki Oei
- Under given assumption the analytical (non iterative) global minimization of distortion maps can be performed solving the set of linear equations.
- Assumptions were tested for the typical distortion in the TPC, moreover the assumption were tested also for the fitted parameters.

Numerical part based on the linear fitting package implemented in the ROOT

Additional functionality implemented in the AliRoot (Alice framework)

- Input data observables and fit models from the tree
- Possibility to add constrains
- Possibility to check the the fit values (return value of the FitPlaneConstrain can be used as a alias in tree)
- Extraction of the partial fits

Distributed computing

Calibration train (Grid) filling of **residual histograms**

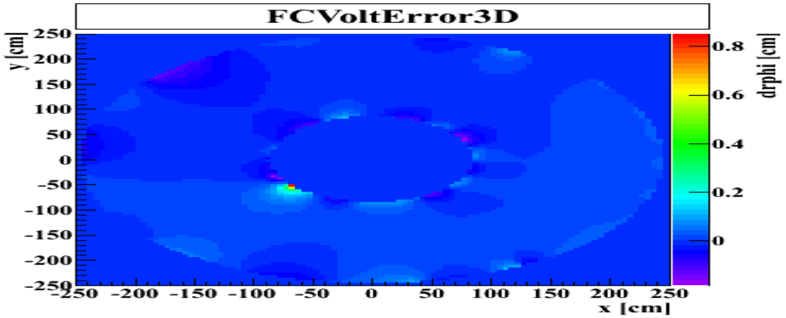
Merging

Creation of **distortion maps**

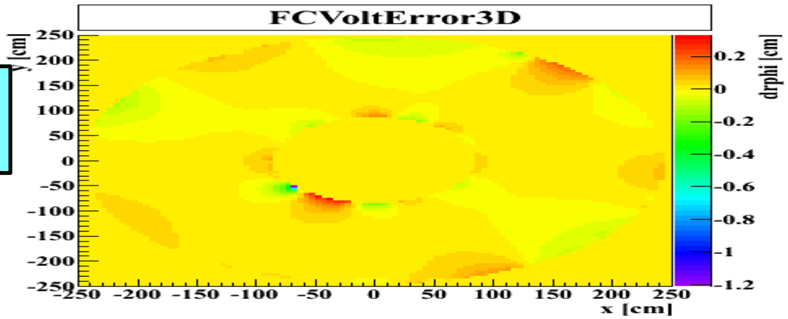
Distortion models fitting

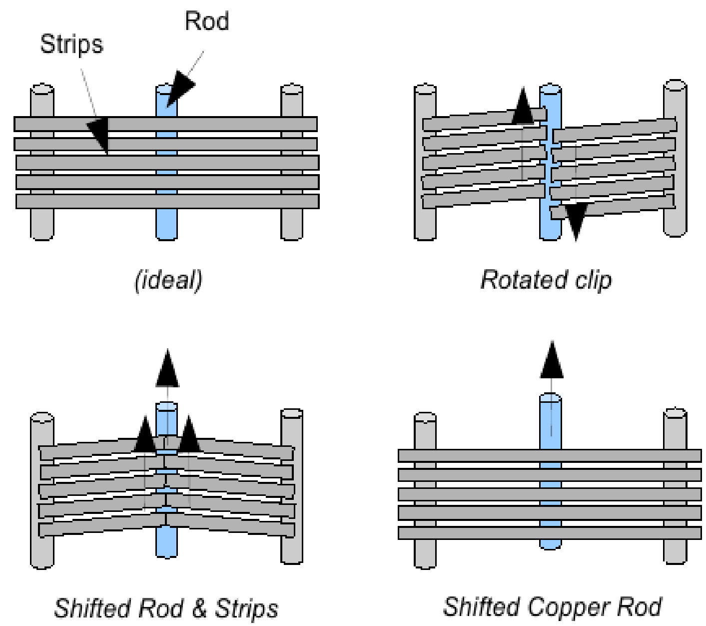
Example distortion fits - Field cage and Rod alignment

A side Positive



C side Negative





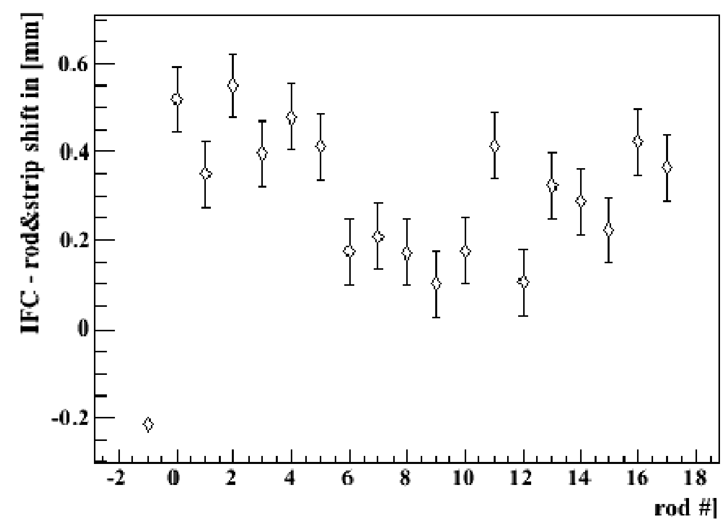
18 (rods) x 2 (IFC,OFC) x 2 (A side, C-side) + 2 rotated clips x 2 (at the resistor rod)

- Small misalignment **(σ ~ 0.1 mm)** leads to a significant non linear distortion up to 6 mm

B field 0 data (4D histograms of residuals between the line and space points) used as a input for the alignment and E field distortion calibration

3D Distortion map obtained from the track residual histograms

- Linear fit with 796 parameters



TPC z coordinate - Drift Velocity Calibration

TPC - drift velocity (v_D) not saturated (Neon based gas, E=400 V/cm)

- $\mathbf{v_d}$ changes strongly with p, T and gas composition.
- e.g $\mathbf{\Delta v_d/v_d \sim 1 \times \Delta P/P - 1 \times \Delta T/T}$

Spatial resolution requirement below 1 mm

- Temperature uniform within ~ 10^{-4}

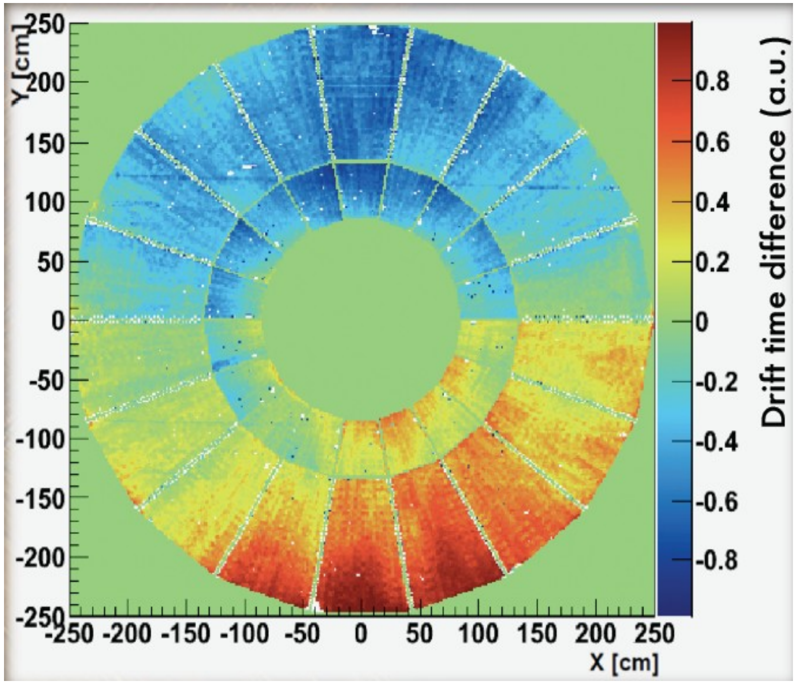
Typical drift variation ~ 5-7 % (10-14 cm)

- Due to the pressure changes – ~ 5 %
- Due to the gas composition changes – ~ 2 %

ONLINE/OFFLINE Calibration:

- Laser data and external v_D monitor (ONLINE)
- Matching of tracks in TPC and ITS(Offline)

P and T measured with seconds granularity, gas composition calibration updated every 15 min

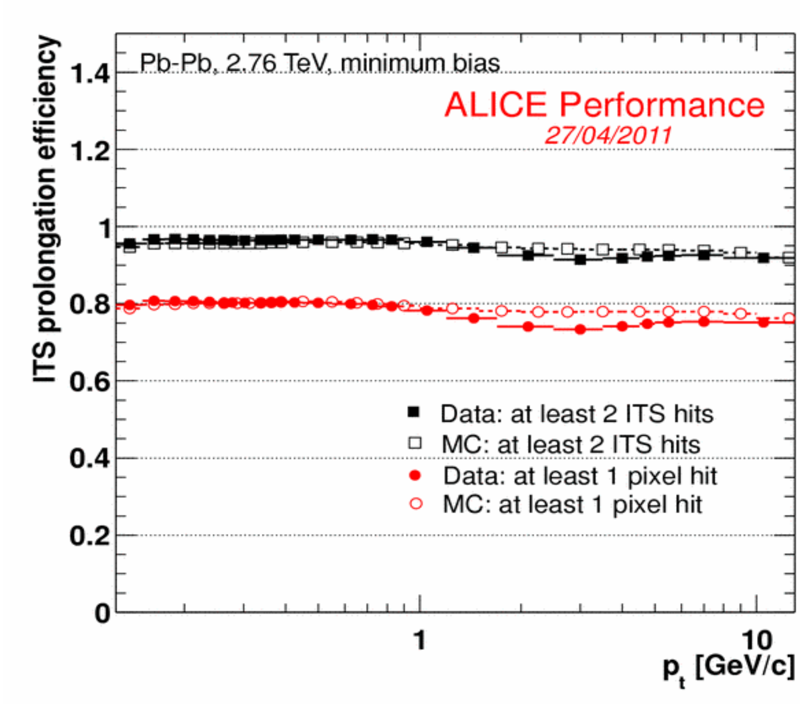


Online calibration example (Laser):

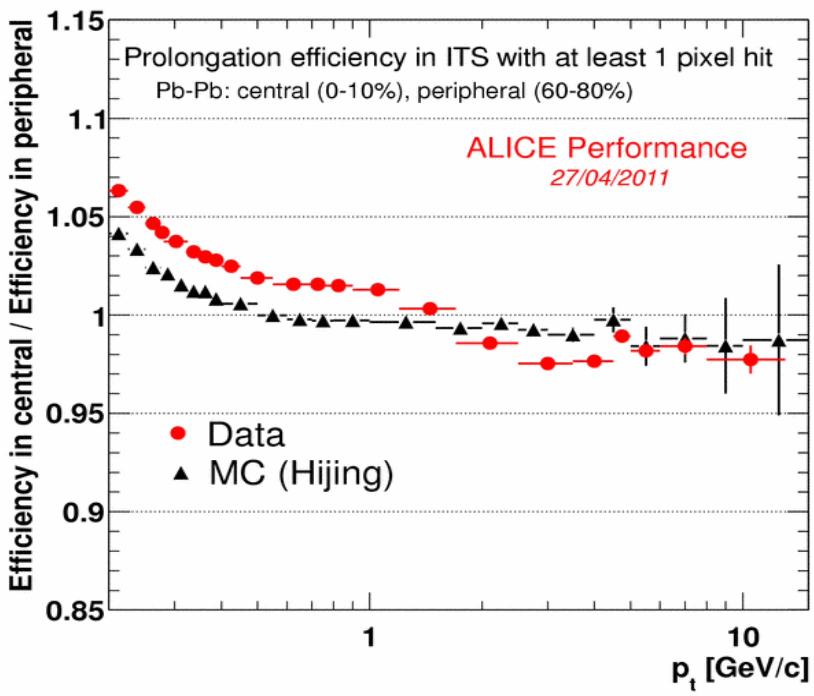
- Photoelectrons knocked out from the central drift electrode by scattered laser light. 1.5 ‰ drift velocity variation observed (due to the vertical temperature and pressure gradient in the gas volume.)
- Linear correction applied later during the reconstruction

Conclusion: Detector performance

Reconstruction efficiency



ALI-PERF-2740



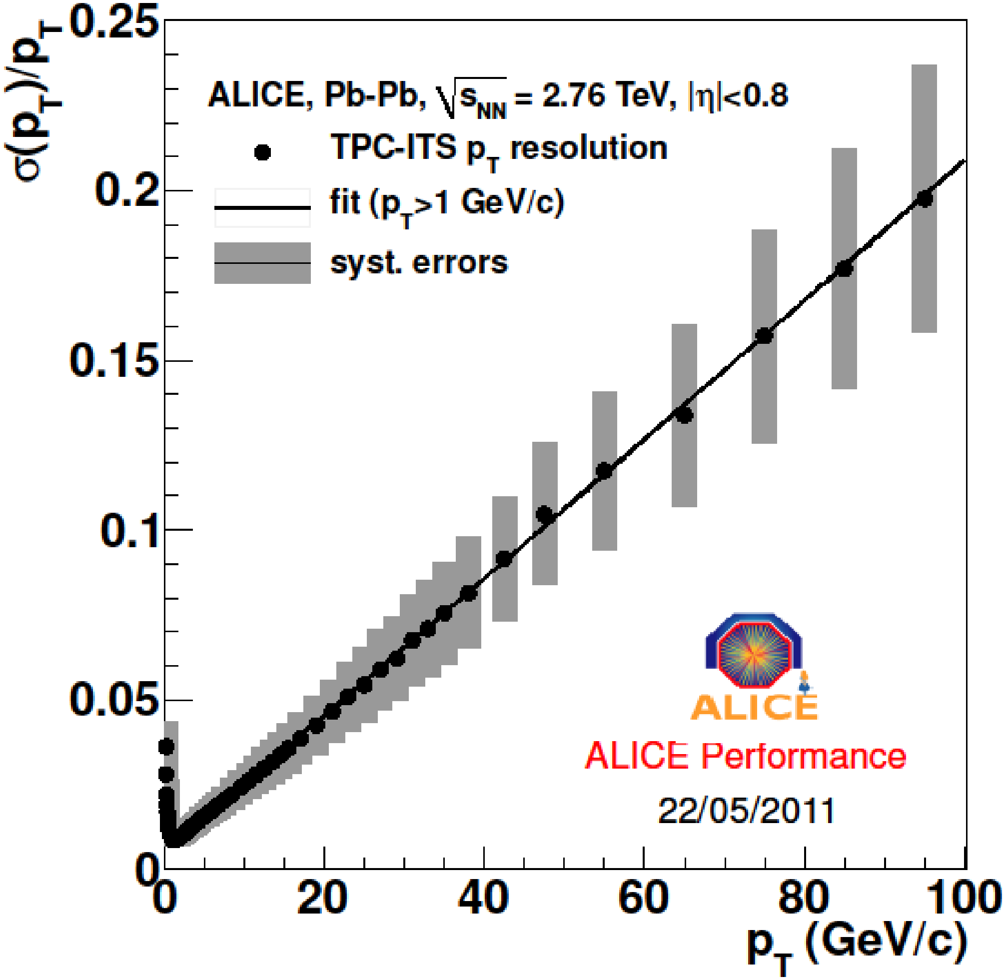
ALI-PERF-2743

The reconstruction efficiency of the TPC tracking for the findable tracks (crossing at minimum half of the TPC) close to 100 %.

Benchmark of the correctness of the MC description- Agreement within 2-3%:

- Track prolongation efficiency in ITS for TPC tracks with standard TPC quality cuts, for the request of ITS refit only (black) and ITS refit with at least a point in Silicon Pixel Detector (red).
- Ratio central/peripheral for the track prolongation efficiency in ITS for TPC tracks with standard TPC quality cuts, for the request of ITS refit with at least a point in silicon pixel detector.

Transverse Momentum Resolution



Pt resolution for TPC+ITS combined tracking

Transverse momentum resolution obtained from combined tracking (TPC & ITS) of 2.76 TeV Pb-Pb collisions (2010)

- **σ_{P_t}/P_t =20% at 100 GeV/c**
- Validated using the K0_s invariant mass spectra (up to 20 GeV) and using the cosmic track matching

Theoretical limit in case of perfect alignment and space point distortion calibration (pp collisions)

- **σ_{P_t}/P_t =5% at 100 GeV/c**

New reconstruction productions close to the intrinsic limit

- Used in the reconstruction productions since September, 2011

OFFLINE reconstruction parallelization

- The strategy for the parallelization of the OFFLINE software not fully defined. Long term strategy under discussion within the OFFLINE group. Currently focused mainly on the simulation part.

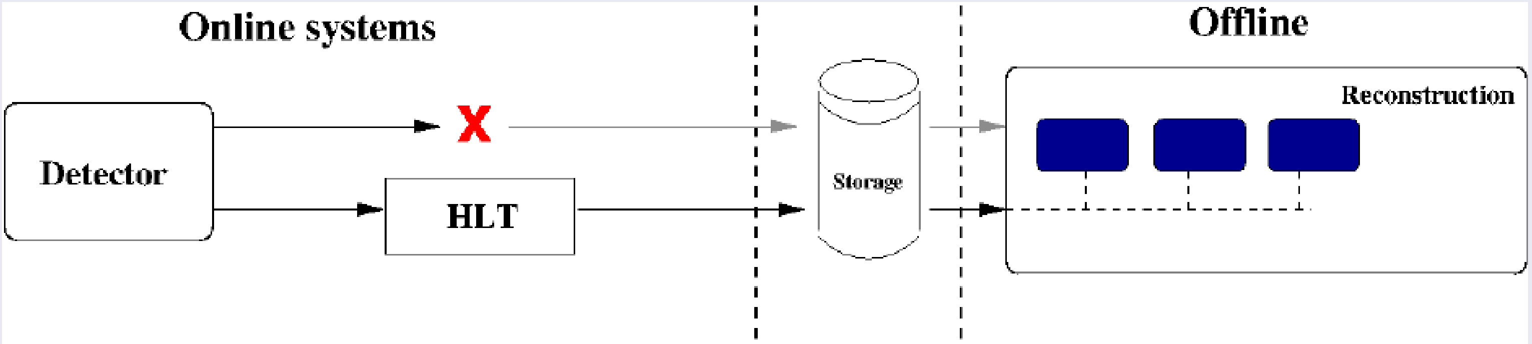
- My personal view - Starting with more active usage of the algorithm optimized for the HLT, e.g:
  - Use online reconstructed space points from HLT in the OFFLINE reconstruction
  - Move part of the calibration form the OFFLINE software to the HLT
  - HLT/OFFLINE common optimized code for the space point transformation material description, B field
  - CA for the track seeding

Data compression with the High-Level Trigger

Figures before 2011 Pb-Pb

- TPC readout time (preliminary): $\sim$ 1.5 ms min bias, $\sim$ 4 ms central
- event size 0-5% central (2010): $\sim$ 80 MB
- assume 200 Hz central $\rightarrow$ 16 GB/s

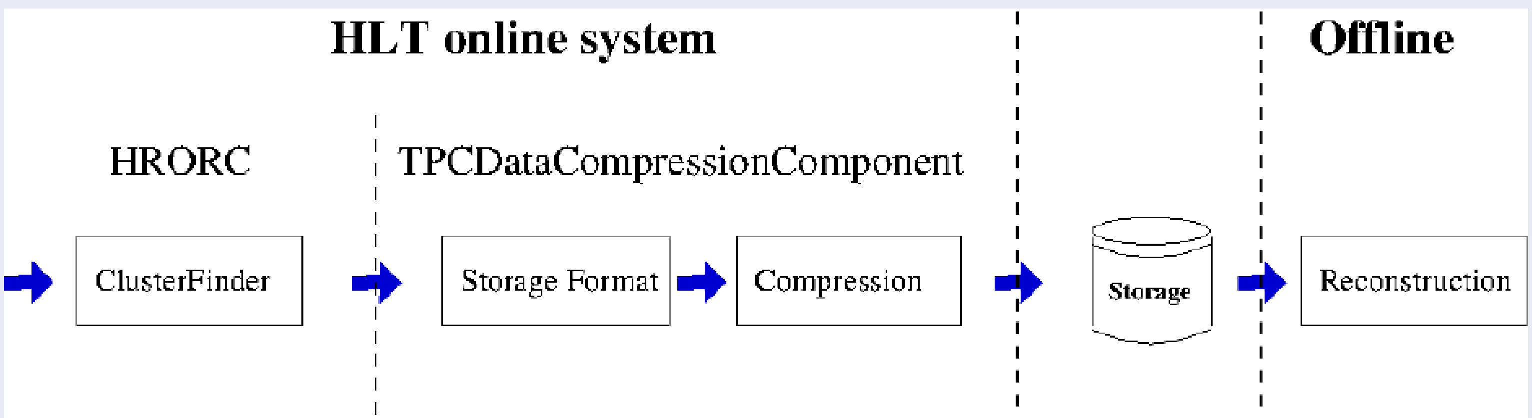
Replacing detector raw data by preprocessed data from HLT



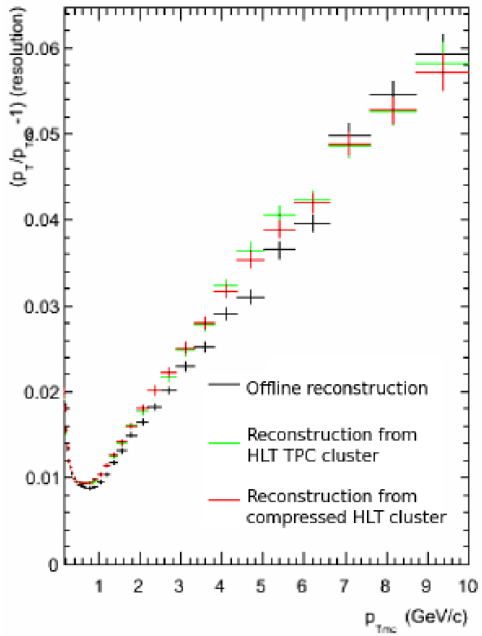
- HLT data can enter detector reconstruction at different stages

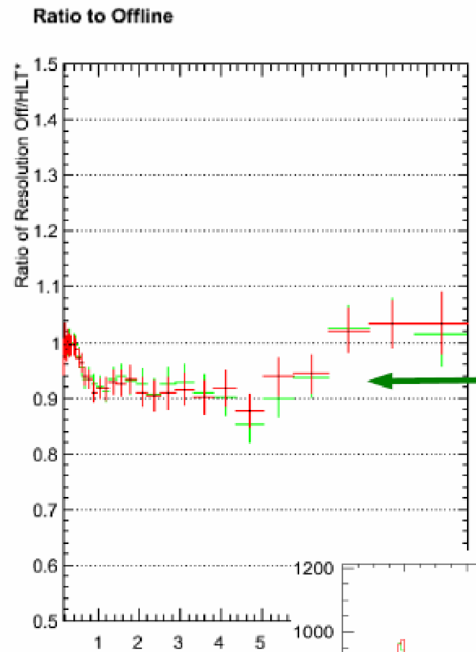
Status - Pb-Pb Data 2011

1. Hardware ClusterFinder
2. Storage format
3. Compression
4. Decoding



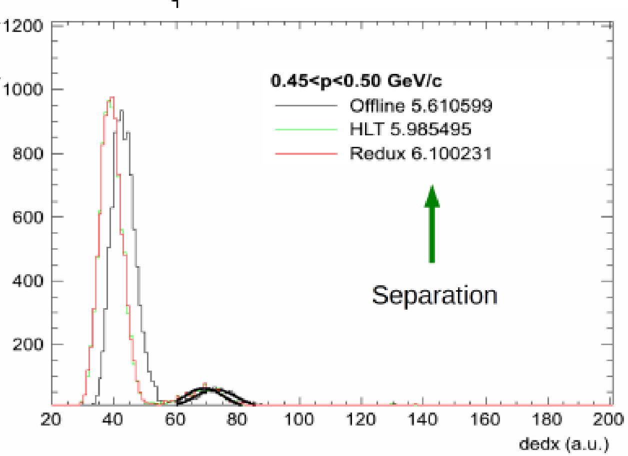
Performance - MC from Oct 2011





MC HIJING central

8% difference
of 3-4% pt resolution



- p_t resolution: 8 % difference
- Identical PID resolution and separation
- Absolute position of pion peak only determined by calibration

Space point correction

Composed corrections

New Composed Corrections

Composed, default OCDB

Environment: 549 ns
1. Misalignment: 422 ns
2. ExB twist: 15 ns
3. ExB effective: 1218 ns
4. ExB B-shape : 2108 ns

Too many corrections - no way to optimize...

Composed, OCDB run 166532

1. TPCExBShape
2. alignGlobal
3. alignLocal
4. alignQuadrant
5. FCVoltError3D
6. FitBoundary
7. FitExBTwist
8. FitAlignTPC
9. FitRocAlignZSum

Space point correction

Transform benchmarks

TPCTransform benchmarks (ns/cluster)

ExB correction is currently used by the HLT
Composed correction is new

Current transform

Total: 680 ns
- **ExB : 300 ns**
- **Rest: 380 ns**

HLT-improved code:

Total: 240 ns
- **ExB : 150 ns**
- **Rest: 90 ns**

New transform

Total: 4690 ns
- **Composed default: 4310 ns**
- **Rest: 380 ns**

Total: 8390 ns
- **Composed last run: 8000 ns**
- **Rest: 380 ns**

Unacceptable speed

Summary

Reconstruction algorithm

- Space point reconstruction before the tracking. TPC and ITS - 2D unfolding.
- TPC reconstruction - standard Kalman filter with seeding in sliced windows. Special effort on the proper error parameterization.
- ITS part - Combinatorial Kalman filter.

Detector calibration and alignment

- ITS alignment using the standard tools (MILLIPEDE)
- TPC calibration and alignment – new calibration/alignment framework developed based on the physical and effective distortion models

Detector performance

- Close to the design values
- Excellent agreement between the MC and real data